TITLE: A Framework for Corrosion Prediction and Management

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ABSTRACT

Technology and economics drive the reduction in life cycle costs for the sustainment of aging aircraft. Technological advances in metal alloys, heat treatments, coatings and processes provide opportunities for longer component life with less frequent inspections to meet the challenge of maintenance cost reductions. Key aspects for the successful implementation of these newer technologies will be discussed. They include a framework to predict corrosion and the development of a corrosion management paradigm.

INTRODUCTION

Environmental degradation of materials and systems is inevitable over the long term. Therefore, the issue of corrosion is not new; however, a renewed interest in corrosion stems from the aging of our equipment in the budget constrained post-cold war era. The cost of corrosion control for our platforms is staggering. It is beyond the scope of this paper to even estimate this cost, and the interested reader is encouraged to investigate various publicly available documents which detail careful cost estimates.

Structural integrity programs have greatly mitigated the risk of catastrophic failure of components by using a thorough understanding of the mechanics of fracture. Although corrosion can result in the eventual condemnation of individual aircraft over time, the overwhelming concerns are controlling existing corrosion and mitigating the risk associated with catastrophic failure induced or exacerbated by corrosion.

As our existing aircraft are being asked to perform beyond their original design lives or for an extensive number of years, the day to day occurrences of corrosion are resulting in higher maintenance costs.

The focus of this paper is to examine and outline the necessary steps to develop a framework for corrosion prediction and provide suggestions for a corrosion management paradigm. The challenges for corrosion prediction and management are:

- To reduce the cost of ownership for current and future aircraft, and
- To provide cost effective sustainment of aging aircraft.

Many will suggest that the prediction, prevention and management of corrosion are too great and that the challenges are too complex. Our current understanding leads us to conclude that corrosion is fundamentally a stochastic process and the complex mechanism remain largely uncharacterized and unmodeled. Even if the mechanisms of corrosion were well understood, there is little chance of obtaining accurate information on corrosion of fielded components nor would it be possible to offer accurate predictions. The problem with this pattern of thinking, although it is hard to argue with such logic today, is that the consequences are astounding. The implication is that corrosion prevention comes at a very high cost of materials, maintenance man-hours, and capital resources. These costs are incurred through the frequent inspections required to find corrosion and the costly repair or replacement programs required as corrective action when corrosion is found.

Table 1 compares and contrasts structural integrity programs and corrosion. Although the fracture mechanics based structural integrity programs are now quite mature, this has not always been the case. Brought about over time, methodologies have been established. Lifing strategies now accurately manage fracture or durability critical components based on a number of parameters tied back to the cumulative flight hours.

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Corrosion is still an immature and largely undeveloped area, not for lack of excellent research but for the lower propensity for catastrophic failure of components. Whereas fracture relates to stresses during the flight profile, corrosion is mainly what occurs between flights in local environments that vary widely worldwide. Although corrosion-prone components are well known or easily established, the corrosion critical components analogous to fracture or durability critical components remain largely uncategorized. Presently, there are insufficient methodologies and collected data available to develop a life prediction strategy. The result is that corrosion continues to be a degradation mechanism that is chased and corrected rather than predicted and managed.

CORROSION MANAGEMENT PARADIGM

There are a number of potential avenues for the development of a corrosion management paradigm. This particular method places the burden on the technology community to develop methodologies to enable corrosion management through risk mitigation, emphasizing similarities with structural integrity programs. The following steps give the basis for this paradigm:

- Develop corrosion methodologies,
- Establish known corrodent species and concentrations,
- Establish corrosion critical or corrosion-prone components for tracking,
- Collect and manage data by aircraft tail number
- Establish smart inspections, and
- Provide opportunities for rapid technology insertion.

Develop Corrosion Methodologies

The largest technological undertaking in this management paradigm is to develop detailed scientific understanding of the various types of corrosion including stress corrosion cracking, pitting, intergranular attack, exfoliation, general corrosion and galvanic couples. The priorities for which types of corrosion should receive priority in research has already been carefully studied and reported by the National Research Council.[1] In addition to specific mechanisms for each variety of corrosion, it is important to establish how various corrosion methods interact and what synergism is introduced.

Once sufficient understanding is developed, it will be necessary to codify life prediction algorithms. With limited understanding, these algorithms may simply be empirical relationships representing data trends. However, additional research may work to establish more fundamental relationships and rules akin to an Arrehenius behavior or corrosion analogue to Miner's Rule.

Establish Known Corrodents

Although it is useful to have standardized corrodents and concentrations, such as sodium chloride or synthetic seawater solutions, for comparing new or improved protective coatings or alloys, these fluids may not be ideally suited for verification of corrosion methodologies. Instead, we can go beyond relying on salt fog or other standardized tests that may be overly conservative for specific applications.

A wealth of data can be gleaned from our existing aircraft fleets. Corrosion-prone areas of aircraft will need to be sampled for corrosion. Specific corrodent species and corrosion products can be obtained during these surveys and, using chemical electrophoresis or other techniques, the active corrodent species and concentrations can be established.

Once corrodent species and concentrations are established, appropriate corrosive mixtures can be formulated and used to verify corrosion mechanisms and methodologies, when developed.

Establish Corrosion Critical Components

Inspection records or discussions with aircraft maintainers may easily identify a number of corrosion-prone components. Such components, with historically known corrosion problems, may be the source of frequently recurring replacement and/or inspection. The original equipment manufacturer may also be aware of likely corrosion-prone components based on the use of alloys or heat treatments that may be more susceptible to stress corrosion cracking, or other types of corrosion. Lastly, there may be severe service environments that may be more prone to frequent corrosive damage. These will depend on the type of aircraft; however, they may include areas near lavatories and galleys, around doors, and in wheel wells.

Although the above list represents corrosion-prone components, these should be distinguished from the more important subset of components that are corrosion critical. A corrosion critical component may be defined as one that is difficult to inspect or repair which can deteriorate over time and be a source of significant systems or vehicle failure. It may also include components that, through corrosion, may result in failure which would be mission limiting.

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[1] National Research Council's National Materials Advisory Board, "Aging of U.S. Air Force Aircraft," NMAB-488-2, 1997.

Collect and Manage Aircraft Data

Collecting sufficient amounts of accurate data is the key to both corrosion prediction and prevention. This data will need to be managed by aircraft tail number to accommodate the specific environments and other data required. Key variable will be established from the corrosion methodology, but will include local service conditions such as temperature, humidity and other weather conditions prevailing at the base or airfield where deployed. To a first approximation, if this data is not available, an index system could be employed, ranking various bases and airfields by their propensity for specific environmental factors leading to corrosion. Aircraft maintenance history will also need to be collected and managed, even to incorporate aircraft washings and the use of corrosion preventive compounds.

It is important that this step not become a logistical burden to maintenance personnel. To the extent feasible, this data should be collected automatically. If possible, smart components should be used. It may be possible to have sensors or data loggers attached or embedded for convenience. Whatever the approach, steps should be taken to minimize the need for data entry to avoid the introduction of errors into the database and to keep costs low.

Establish Smart Inspections

To keep the costs of ownership in balance, it is imperative that we avoid:

- Establishing rigid inspection intervals where unnecessary. A first look at this approach, it seems quite obvious that planes in relatively benign corrosive environments may benefit provide cost savings by having broader inspection intervals.
- De-painting for inspection. As better NDI techniques are developed and as corrosion prediction methodologies improve, it will be best to let protective coatings, primers, and topcoats provide the corrosion protection without interruption for unnecessary inspection.
- Reverting to finding and fixing corrosion. Although there is a great deal of momentum to continue with finding and fixing corrosion, the high cost of inspection and premature repair is not the long-term, cost effective solution to the corrosion problem.

By avoiding the pitfalls listed above, it will be easier to develop and implement smart inspection strategies. These will include the use of predicted corrosion rates methodology to identify critical inspections of corrosion critical components. These will not be generically applied to all aircraft based on time in service, but will take into account the service environment for the specific aircraft, by tail number. The long term smart inspection strategy will be to use sensor data to trigger inspection or, better yet, component replacement. Provide Rapid Technology Insertion

Involve the technology community in ways to reduce the cost of ownership for aging and future aircraft platforms. This may entail close coordination with the original equipment manufacturer and supplier base. All due consideration should be given to the practical application of technological advancements. Some of these may include:

- New corrosion resistant alloys,
- Heat treatments for new or existing alloys that may reduce the risk of SCC or other types of corrosion,
- Environmentally-acceptable coatings,
- Faster and more durable repair processes, and
- Non-destructive techniques that can further increase the interval between inspections.

SUMMARY

A complete corrosion management paradigm has been outlined which is based on technology drivers to advance the basic understanding of corrosion mechanisms, and provide a methodology of corrosion to enable corrosion-based life prediction. In addition, fielded aircraft should be the basis for establishing known corrodents and their concentrations for verification of corrosion methodologies developed. The burden falls on the aircraft owners, with the recommended enlistment of the original equipment manufacturer, to identify and establish corrosion critical components for tracking in an extensive database which incorporates the latest in networking and information technology. Inspections are not to be established by the calendar, but by the culmination of the established methodology and accurate data for corrosion critical components. An overarching consideration is the rapid integration of technological advancements that may provide improved component life and be effective for the total cost of ownership.

Table 1: Comparison of Structural Integrity Programs and Corrosion

Structural Integrity	Corrosion
Identifiable fracture critical or durability critical components	Corrosion critical components not identified
Based on cumulative flight hours	Primarily related to non-flight hours
Established methodology	Insufficient methodology established
Fleet Data Tracking	Insufficient data collection and/or management
Predicted and managed	Currently a “find and fix” approach